A new global tropical cyclone data set from ISCCP B1 geostationary satellite observations

Running Title: NEW TROPICAL CYCLONE SATELLITE DATA SET

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Abstract

In light of recently documented hypotheses relating long-term trends in tropical cyclone (TC) activity and global warming, the need for consistent reanalyses of historical TC data records has taken on a renewed sense of urgency. Such reanalyses rely on satellite data, but until now, no comprehensive global satellite data set has been available for studying tropical cyclones. Here a new data record is introduced that will facilitate the reanalysis of TCs by providing satellite imagery in a standard format for the period of record 1983 to 2005. The data are collected from Japanese, European and U.S. geostationary satellites and the infrared channel data, which are particularly relevant for TC analyses, have been recalibrated to reduce inter-satellite differences. Observations are provided on a 0.07°×0.07° (~8km) Lagrangian grid that follows the TC center. The data set will be updated annually and work is also underway to expand the data set backward to the late 1970s.

Introduction

The existing historical records of tropical cyclones (TC) generally comprise measurements or estimates of storm-center position and maximum wind every 6 hours for the life of each storm [*Chu, et al.*, 2002; *Neumann, et al.*, 1999]. Because of changes in the available data and analysis techniques applied to the construction of these records, there is an inherent lack of temporal consistency in the data. There are ongoing efforts to create more homogeneous data records through careful reanalyses of various data sources (e.g., [*Landsea, et al.*, 2004]) Estimating tropical cyclone intensity from satellite imagery is an integral part of this process (e.g. [*Dvorak*, 1984; *Olander and Velden*, 2007; *Velden, et al.*, 1998]). However, until recently there were no comprehensive satellite data resources available for a global reanalysis. Instead, tropical cyclone imagery had to be obtained from small collections which cover only portions of the global oceans (e.g., [*Zehr*, 2000] or http://www.digital-typhoon.org).

Alternatively, global satellite data can be obtained from the operational archives, which is less appealing for numerous reasons. First, depending on the scale of the study, orders from up to three archives[1] from three countries must be managed. Second, full resolution data would likely be obtained which are costly to download, store, and process because of bandwidth, storage, and processor considerations, respectivley. Third, TC imagery would be processed from the full resolution data, which could require mastering

[1] Raw geostationary data are available from EUMETSAT (http://archive.eumetsat.org/), JMA (http://mscweb.kishou.go.jp/data_archiving/) and NOAA (http://www.class.noaa.gov/), each with its own method for querying the inventory, ordering the data, and downloading the files.

many data formats and navigation algorithms. Fourth, preliminary work of ensuring consistency between different satellites within a series and between different series would be necessary. Clearly, there is a need for a better alternative for global tropical cyclone research.

Here we introduce a new data record of tropical cyclone-centered geostationary satellite imagery which has been carefully reanalyzed to remove time-dependent biases and inter-satellite variations. The data are global and span the period 1983 to 2005. The data record was constructed in a collaborative effort between the National Climatic Data Center (NCDC) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison. It consists of a subset of observations from the International Satellite Cloud Climatology Project (ISCCP) B1 data record.

ISCCP B1 data characteristics

The B1 period of record begins with the ISCCP project in July 1983. Since then, global satellite data have been archived at the NCDC from the U.S. Geostationary Operational Environmental Satellite (GOES), Japanese Geostationary Meteorological Satellite (GMS) and the European Meteosat series. The B1 record is ongoing and will include more satellites as data become available. The data include observations from all available channels. This includes infrared window (~11 μm) and visible (~0.6μm) channels for the entire period of record from all satellites. Other channels include water vapor (~6.7μm) observations (on Meteosat since 1983 and globally since 1998) and the near-infrared (~3.9μm) and split window (~12μm) channels from the newer GOES series (beginning with GOES-8). The data were collected at the ISCCP satellite processing centers where imagery were sampled to nominally 8 km spatial and 3-hourly and temporal resolutions. Also, radiance observations were converted to 1-byte values which required degrading data from instruments with higher bit-depth (e.g., 10-bit data from GOES-8). Data were then archived at the NCDC where they are now being prepared for use in the ISCCP cloud climatology reanalysis and other climate applications.

The spatial coverage of the B1 data (Figure 1) is generally global. The gap over the Indian Ocean ends when Meteosat-5 began observations there in 1998. Other gaps exist where satellites failed (e.g., GOES-5 and 6). Given the heterogeneity of the satellite instruments and their spatial coverage, much effort went into making the data temporally consistent.

Data processing

Processing the ISCCP B1 data into a TC-centric data set required two primary steps: ensuring the observations are temporally consistent and creating a subset of the data focused on global tropical cyclones.

A significant concern in providing such a data set is the temporal stability of the observations, particularly the infrared window brightness temperature observations which are used to estimate tropical cyclone intensity (e.g.,[*Dvorak*, 1984]). All geostationary satellites have an on-board black-body calibration reference for infrared observations. Nonetheless, there are some inter-satellite variations in the calibration which the ISCCP project removed via normalization to a reference polar-orbiting satellite (the Advanced Very High Resolution Radiometer, AVHRR) [*Brest, et al.*, 1997; *Desormeaux, et al.*, 1993]. *Knapp* [2007], then, independently calibrated the B1 infrared brightness temperatures from the ISCCP calibration against a second reference instrument: the High-resolution Infrared Radiation Sounder (HIRS). Errors were found in the ISCCP calibration resulting from a poorly documented format change by the AVHRR data provider, so a calibration correction was applied. Monthly comparisons of the original ISCCP calibration and the correction using HIRS are shown in Figure 2. The biases after the correction are much closer to zero. The result is a temporally-consistent brightness temperature record appropriate for TC analysis.

Since the B1 data include 1.4 TB in more than 250,000 files, a subset is needed to facilitate TC research. Global TC positions were obtained from the tropical cyclone databases maintained by the National Hurricane Center (e.g., HURDAT) and the Joint Typhooon Warning Center (JTWC) [*Chu, et al.*, 2002]. These data are collectively called best-track data. To match the temporal resolution of the best-track data with the B1 data, TC positions were interpolated to 3-hourly resolution using cubic splines [*Kossin*, 2002]. Data were then interpolated to a Lagrangian grid whose center followed the tropical cyclone circulation center. The 0.07° grid resolution corresponds to ~7.8 km latitudinally and 3.9 to 7.8 km longitudinally (see Table 1) which is similar to the native ISCCP B1 resolution. The grid size is 301×301 elements and spans a 21°longitude by 21°latitude TC-centered box that is typically large enough to observe the various sizes of tropical cyclones and their immediate environments. Also, when a tropical cyclone is observed by two satellites, both observations are retained along with their view zenith angles relative to the TC center position. This allows for future analyses investigating inter-satellite bias or view zenith angle dependence.

The tropical cyclone satellite data set

The global tropical cyclone data set is archived at NCDC and made freely available[2]. The data are provided in netCDF format, following standard conventions to allow interoperability and ease of use. The data consist of ~169,000 observations of 2046 tropical cyclones from 1983 through 2005.

The global extent of the data set is shown in Figure 3. Observations within 250 km of a tropical cyclone center were counted, providing the spatial distribution of the 2046 cyclones in the data set. The primary drawback of the data set is immediately apparent: a gap in observations over the Indian Ocean. Here, a 75° view zenith angle limit leaves an 8° gap between observations by Meteosat over the Prime Meridian and GMS at 140° East longitude. Conversely, the Pacific and Atlantic Oceans are more continuously observed.

The spatial coverage directly affects the amount of missing data, which are summarized in Table 2. The missing values were calculated by counting the times during which a tropical cyclone existed but no corresponding satellite data were available. Overall, the first decade had more missing observations than later decades. Periods with more missing data correspond to satellite coverage gaps, such as the Indian Ocean and Eastern Pacific basins in the 1980s. Nonetheless, the percentage of missing observations for the 2000s is 0.02%, or 1 missing observation for every 474 observations.

[2] NCDC data set #3641 described at http://www.ncdc.noaa.gov/oa/rsad/b1utc/b1utc.html

Discussion and Conclusion

This new data record has been recently applied to the reanalysis of global trends in tropical cyclone activity. The accuracy of recently documented trends [*Emanuel*, 2005; *Webster, et al.*, 2005] was in question based on the heterogeneity of the existing tropical cyclone records [*Landsea*, 2005]. To address this, [*Kossin, et al.*, 2006] applied the homogeneous satellite data to the estimation of TC intensity and formed a new intensity record that was used to reanalyze the trends.

The value of these data might be further enhanced by extending the period of record beyond 1983 to 2005. Efforts are underway to extend the coverage back in time, potentially to 1981 for GMS and 1977 for GOES. Also, the data will be updated annually with the most recent TC locations.

However, some limitations of this data set can not be overcome that would require new data processing. If the spatial or temporal resolutions are not sufficient for particular studies, then data from the archives would have to be obtained for further analysis. In general, 4km infrared imagery at 30 minute intervals are available from the global archive centers. However, it comes at a price: the needed bandwidth, disk storage, and CPU. The benefit of only doubling the spatial resolution or sextupling the temporal resolution would have to be weighed against this cost. Another limitation is the lack of geostationary coverage over the Indian Ocean. An alternative would be to construct a similar TC-centered data set from the AVHRR record for the Indian Ocean. The value of which has already been shown by *Landsea et al.* [2006].

The key result of this work is a new "one-stop" data set useful in tropical cyclone research because of the calibration work to ensure temporal consistency and the tropical cyclone-centric subsetting to facilitate processing.

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Tables

Table 1 - Longitudinal (east-west) ground resolution of the 0.07° grid

Latitude (°)	Resolution (km)
20	7.3
40	6.0
60	3.9

Table 2 - Percent of missing tropical cyclone geostationary data grouped by decade and ocean basin.

	Indian Ocean	Southern Pacific	Western Pacific	Eastern Pacific	Northern Atlantic
1980s	12.7	8.0	7.6	7.3	5.5
1990s	3.0	2.3	0.6	4.0	1.6
2000s	0.2	0.2	0.1	0.0	0.5

Figures

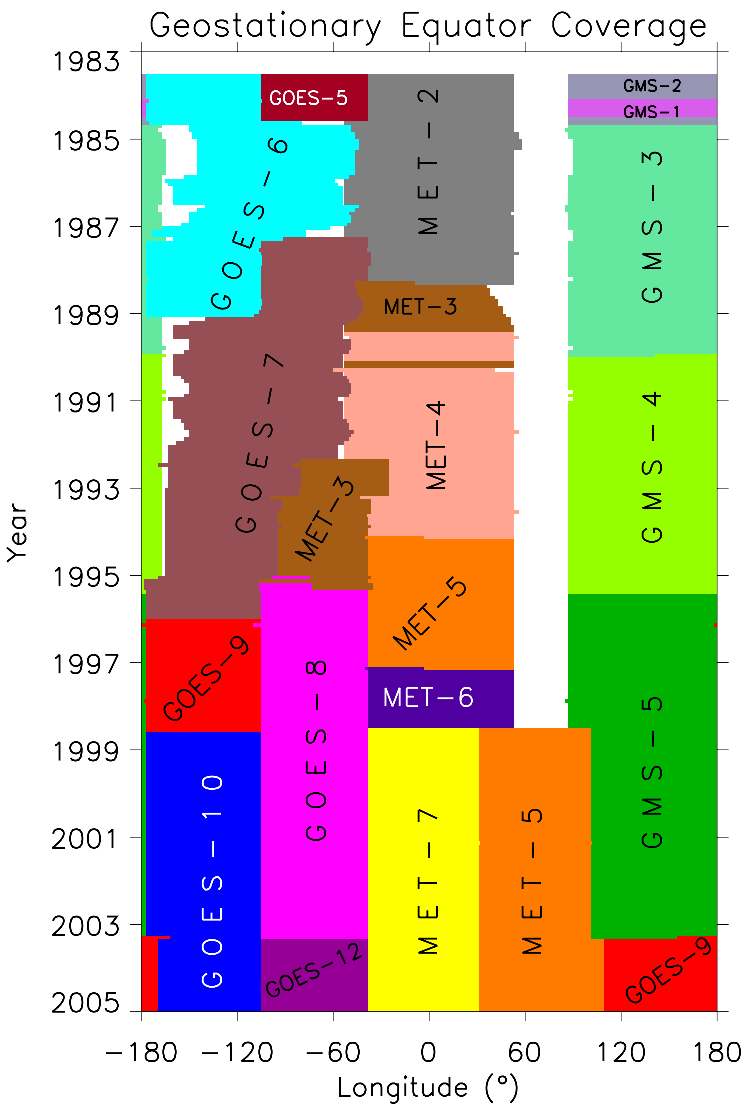

Figure 1 - Temporal and spatial Equatorial coverage from the geostationary satellites which make up ISCCP B1 data (shading is limited to a view zenith angle less than 60° for illustrative purposes).

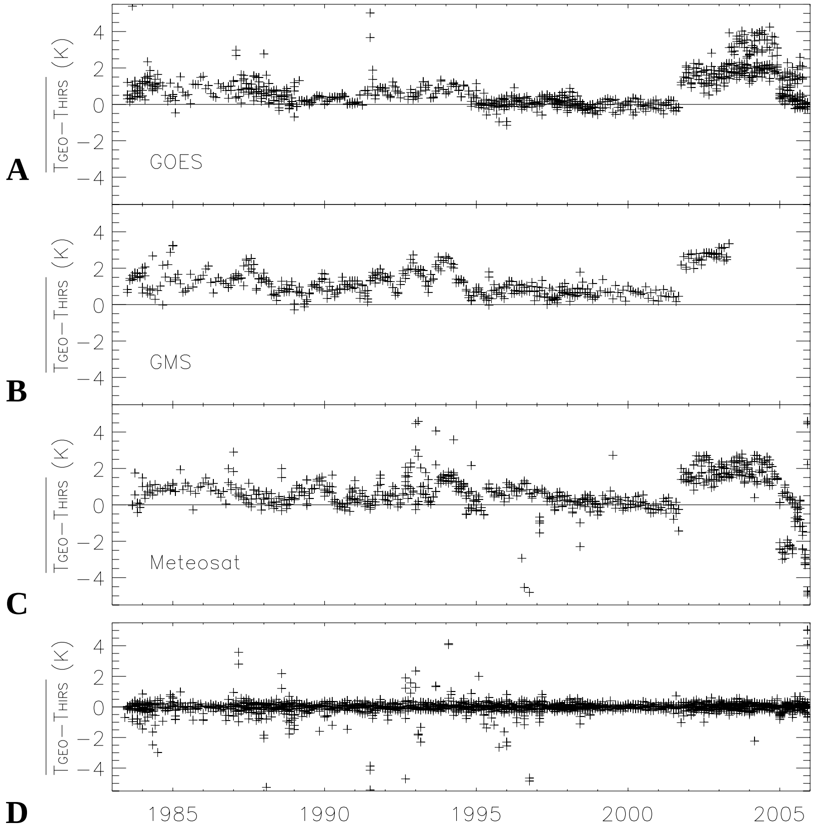

Figure 2 - Initial monthly average difference between HIRS (T_{HIRS}) and geostationary (T_{GEO}) brightness temperatures for A) GOES, B) GMS and C) Meteosat satellites. D) Monthly average difference after calibration correction for all satellite series.

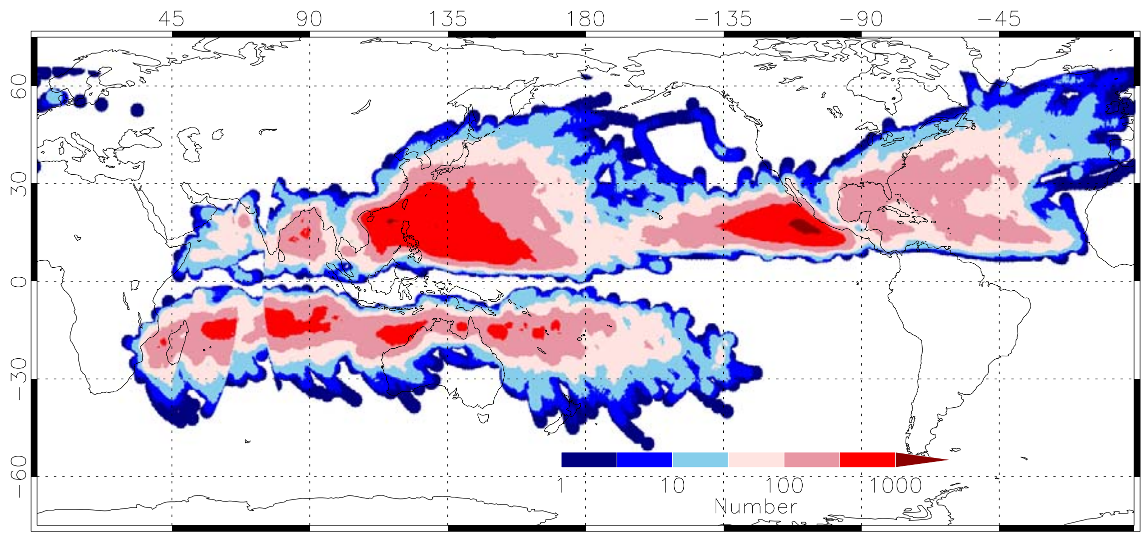

Figure 3 - Spatial distribution of the number of observations within 250 km of a tropical cyclone for 1983-2005. The relatively data-void region in the S. Indian Ocean was not well-sampled until the Meteosat 5 coverage data began there in 1998.